# GIS APPLICATIONS IN WATER RESOURCES USING GRASS

By
T. SURYA PRAKASH



DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

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# G.I.S. APPLICATIONS IN WATER RESOURCES USING GRASS

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*T.Surya Prakash*

**Department of Civil Engineering**
**Indian Institute of Technology Kanpur**
**India**

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DEDICATED

TO

AMMA AND NANNA

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Prakash. T Surya

# CERTIFICATE

It is certified that the work contained in the thesis titled " G.I S. Applications in Water Resources using GRASS", by **T.Surya Prakash** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree

**Dr S.Ramaseshan**
Professor
Department of Civil Engineering
IIT Kanpur

May, 1995

# Abstract

The Geographic Information Systems ( G I.S ) are a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes Presently it is increasingly used by the hydrologist for spatial data analysis and decision making GRASS (Geographical Resources Analysis Support System) is a raster based G I S. developed by USACERL and is available for study The additional components of this software are implemented at SPARC LX workstation at Water Resources Engg and Management centre, Department of Civil Engineering, I I T Kanpur. Then GRASS was used for the spatial data base development of Ganga River Basin between Kanpur and Allahabad and for the ground water balance analysis of this region The maps are prepared according to the requirements, from the maps collected from U.P. Irrigation Department. These maps are scanned and then digitized using the on screen digitization capabilities of GRASS (*v.digit*). Then the raster maps of the study region, Rain gauging stations, Districts in the study region, Ground water measurement stations, Irrigation Blocks, Channel Networks, Main rivers etc , are prepared using the program *v.to.rast.*

The normal rainfall values for monsoon and nonmonsoon season are calculated at each rain gauge station and are implemented in the data base. Further these rainfall values are used to interpolate the rainfall distribution in the study region. this interpolation is done using the utility *r.surf.idw.* Similarly the pre monsoon and post monsoon ground water table values at different monitoring stations are collected and are used to interpolate their distributions over the entire study region

From the topographic map of the study area the topographic elevations at different points are estimated using the program *r.surf.idw.* The ground level contours are drawn from this interpolated surface.

Contours of rainfall and ground water table levels for both the seasons and the topographic contours are extracted from their interpolated surfaces. The depths to ground water table at differnt irrigation blocks are calculated.

The average rainfall values in different districts, irrigation blocks and in the entire study area is calculated for the two seasons Different components of ground water balance are calculated and using a lumped model approach an approximate ground water balance study has been carried out for the study region.

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# Chapter 1

# Introduction

## 1.1 General

Traditionally decision making process in Water resources management and planning has been assisted by a multiplicity of decision support tools, including mathematical models for simulation and optimization, statistical routines for analysis and interpretation of data and database management systems Recently with the advent of ever increasing computer power, Geographic Information Systems(GIS), have been added to the body of the tools that are intended to support the decision processes through their many steps.

Today large Geographical Information Systems are being developed, operated , continuously updated and further refined by various environmental and water agencies.This emerging new technology was developed at first mainly from multiobjective representing,structuring and mapping of multivariate spatial data The GIS potential is now being realised not only in inventory application but also in studies which apply simulation models. Tailored to a special problem region of interest and confined to the set of problems relevent data and models, a GIS can be applied both as a data platform for simulation model as well as an interactive user environment for daily routine water management in smaller agencies. In many cases, however, GISs are laid out to serve as multipurpose, nearly "catch all" data management systems with numerous possible applications, ranging from hydrological and environmental studies, through land use and economical investigations up to support of urban development

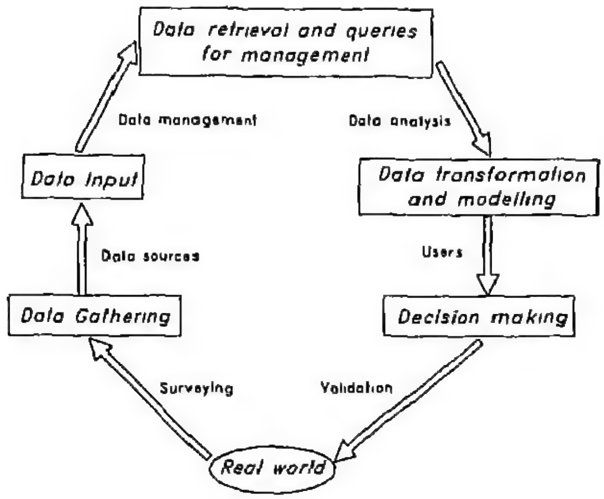


Figure 1.1: Database Management in GIS*(Valenzuela)*

and transport planning.

*Leanfear*'s(1989) editorial in Water Resources Bulletin concludes that, "The impact of GIS may be as significant as the introduction of FORTRAN, as scientists learn to use and manipulate spatial data to contribute to new level of understanding of environmental issues". Although not enough time has been elapsed to accurately assess this claim, the potential application of GIS to Water Resources is indeed great

GIS are used to assist decision makers by indicating various alternatives in development and conservation planning and modeling the potential outcomes of series of sceneries as shown in Figure 1.1.

Computerized mapping and spatial analysis has been developed simultaneously in several related fields such as,

- Cadastral and topographic mapping.
- Thematic cartography.
- Civil Engineering

- Geography
- Hydrology etc..

### 1.1.1 Typical GIS applications:

- automatic cartography
- subdivision design(cut/fill. street and parcel layout)
- cadastrel mapping
- highway mapping
- utility and facility mapping and management.
- geodesic mapping
- event mapping
- census and related statistical mapping
- management of well log data
- land use planning and management
- marketing and retailing
- vehicle routing and scheduling
- urban and regional planning
- route selection of highways, pipelines and similar data
- water resources planning and management
- surveying and engineering
- mineral exploration.

**Current types of G.I.S.s :**

Current types of GIS are grouped into:

- engineering mapping systems (CAD/CAM) for applications in photogrammetry, topographic base maps and road engineering.
- property of parcel information systems
- generalized thematic and statistical mapping systems for natural resources management, forest inventories, vegetation, geology, soils, census mapping
- geographic base file systems associated with street networks
- image processing systems

## 1.2 Definitions of G.I.S.

There have been a number of attempts to define a Geographic Information Systems(GIS), and two main themes can be distinguished, technological and problem solving The technological definition typified by the followings, concentrates on the computer related aspects of the field, and has dominated the literature till to date*(Curren, 1984,Marble, 1984,Parker, 1988)*

**Definition 1:**

Geographical Information Systems are a powerful set of tools for collecting, storing,transforming and retrieving at will and displaying spatial data from real world for a particular set of purposes *(Burrough, 1986, p.6)*

More recent definitions have concentrated on problem solving aspect of GIS. Thus*Goodchild (1985)* gives the following definition.

**Definition 2:**

A GIS is best defined as a system which uses a spatial database to provide answers to queries of a geographical nature.

This emphasizes the analytical nature of the system. An emphasis on problem solving nature has been presented by *Cowen(1987)*

**Definition 3:**

A GIS is a decision support system involving the integration of spatially referenced data in a problem solving environment*(Cowen 1988 p 1554)*

## 1.3 Inter Relationships Among Cartography, Remote sensing and GIS

The model illustrated in the Fig. 1 2 is presented as the most realistic representation of the interaction among the three fields as currently practiced No field is placed in a position of dominance one over the other, or indeed in isolation, but there is interaction in all possible combinations of the three Data acquisition and data analysis are the emphasis in remote sensing. With in remote sensing however , consideration must be given to the destination of the information gathered, which may either be used as input to a GIS or be represented in a graphic form. Furthermore, the computer system used in modern digital image analysis have much in common with GIS processing, such that many vendors have, without changing the data structures, implemented GIS function in their image processing system Clearly, then, remote sensing does impinge on the domains that might otherwise be recognized as GIS and cartography, respectively

The analysis of geographic information to support decisions, which is the main concern of practitioners of GIS, is dependent on the way in which the data are gathered. When data are derived from remote sensing, quality and organization are dependent on the methodology in that field. Similarly while GIS professionals are not primarily concerned with the quality of the graphics that may be derived from the information, they should be cognizant of the implications of the data manipulations upon the message presented in a resultant map. The cartographer may map information which is a direct product of remote sensing or which have been processed by a GIS. In this model, the emphasis within cartography is the effective presentation of the information as a map, and includes data analysis and manipulations to facilitate that presentation.

The relationship of remote sensing and GIS with cartography in this model is not unlike the traditional view of data acquisition and data manipulation as precursor

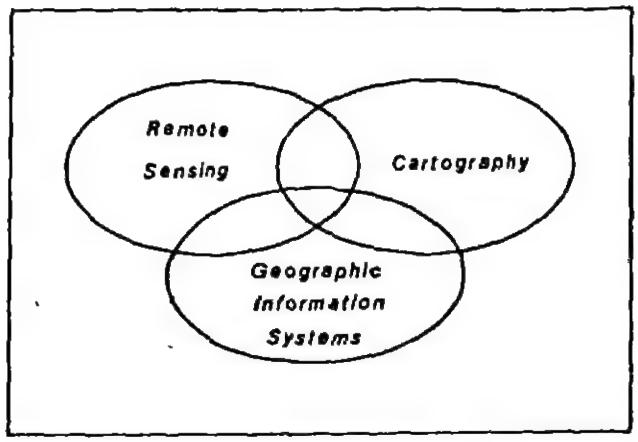


Figure 1.2: Model of three way interaction of Remote sensing, Cartography and G.I.S *(Burrough)*

of the map. The three way interaction model, however, depicts a relationship that recognizes larger subsideries of cartography Remote Sensing and GIS have a body of knowledge and require a level of expertise such that it is no longer realistic to envisage a cartographer as being expert in these areas as well. Thus the relationship of the fields requires not only that the definitions are reasonable but also they reflect the nature of the interactions. A set of revised definitions are suggested

**Cartography:**

Cartography is the field which is involved with the graphic communication of spatial relationships and distributions, and includes the analysis and manipulation of geographic data to enhance representation.

**Remote Sensing:**

Remote sensing is the capture and interpretation of data from regions of the electromagnetic spectrum through the use of noncontact instruments together with analysis and manipulation to facilitate interpretation.

**Geographical information systems:**

GIS is defined as the management analysis and manipulation of spatially refer-

enced information in a problem solving synthesis By observing the above definitions, Analysis and manipulation appears to be forming the common theme

In cartography analysis and manipulation involves in the processes of projection change and line generalization and finding the chloropleth map intervals. In remote sensing cluster analysis of reflectence forms the analysis and manipulation part And in GIS overlay analysis and Zone buffering forms the important phase of analysis and manipulation

## 1.4 Components of G.I.S.

Geographical Information Systems have three important components, computer hardware, set of application software modules and a proper organizational context. These three components need to be in balance if the system is to function satisfactorily.

Computer hardware components of a GIS are presented in Fig.1 3 The computer or the central processing unit(C.P.U.) is linked to a disk drive storage unit, which provides space for storing data and programs A digitizer or other device is used to convert data from maps and documents into digital form and send them to computer A plotter or other kind of display device is used to represent the result of data processing, and a tape drive is used for storing data or programs on magnetic tapes, or for communicating with other systems The user controls the computer and its peripherals via a visual display unit(V D U), otherwise known as a terminal. The user's terminal might itself be a micro computer, or it might incorporate special hardware to allow maps to be displayed quickly.

## 1.5 G.I.S. software modules

The software package for a GIS consists of five basic technical modules (Fig.1.4). These basic modules are subsystem for :

- Data input and verification
- Data storage and database management.

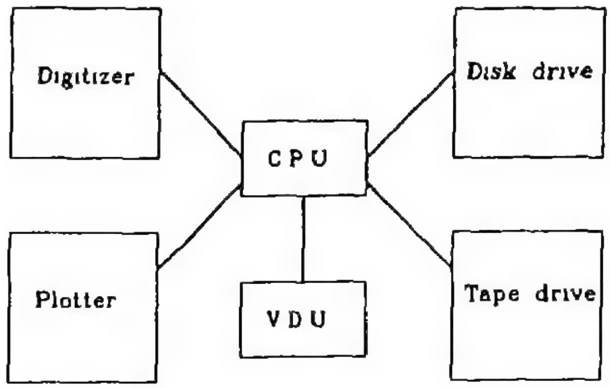


Figure 1.3 Hardware components in a GIS *(Burrough)*

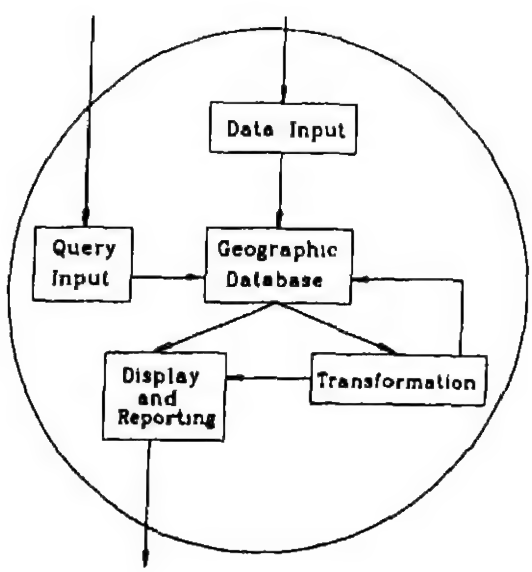


Figure 1.4: Main software components in a GIS *(Burrough)*

- Data output and presentation
- Data transformation
- Interaction with the user

Data input(Fig 1 6) covers all the aspects of transforming data captured in the form of existing map, field observations and sensors( including aerial photography, satellites and recording instruments) into a compatible digital form A wide range of computer tools are available for this purpose, including the interactive terminal or Visual Display Unit (V D U) The digitizer lists the data in a text file, scanners (in satellites or aero planes direct recording of the data or for converting maps to photographic images) and devices necessary for recording data already written on magnetic media such as tapes, drums and disks.

Data storage and database management(Fig 1 5) concerns the way in which the data about the position, linkage(topology) and attributes of geographical elements (points,lines,and areas representing objects on earth's surface) are structured and organised, both with respect to the way they must be handled in the computer and how they are perceived by users of the system The program used to organise the database is known as database management system (DBMS)

Data output and presentation(Fig 1 6) concerns the ways the data are displayed and the results of the analysis are reported to the user. Data may be presented as maps, tables and figures in a variety of ways ranging from the ephemeral image on a Cathode Ray Tube(CRT) through hard copy output drawn on printer or plotter to information recorded on magnetic media in digital form.

Data transformation(Fig.1.7) embraces two classes of operation, namely (a) transformation needed to remove errors from the data or to bring them up to date or to match them to other data sets and (b) the large array of analysis methods that can be applied to the data in order to achieve answers to the questions asked to the GIS Transformation can operate on spatial and non spatial aspects of the data, either separately or in combination. Many of these transformations, such as those associated with scale-changing, fitting data to new projections, logical retrieval of data and calculation of area and perimeters are of such general nature that one should expect to find them in every kind of GIS in one form or another.

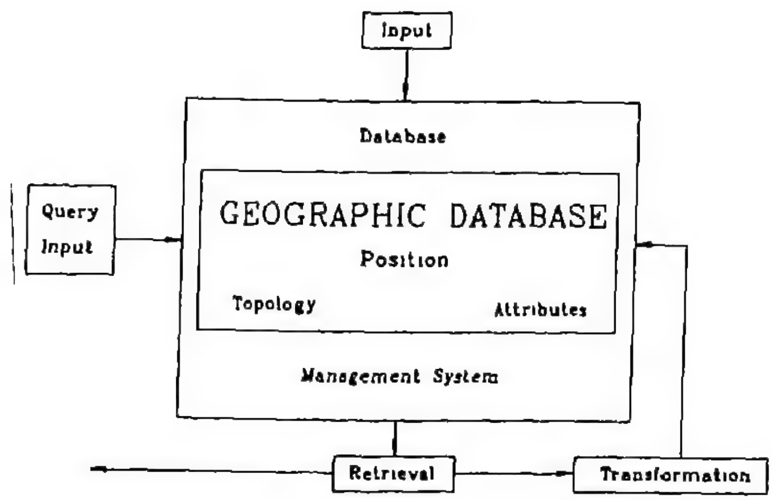


Figure 1.5 The Components of a GIS *(Burrough)*

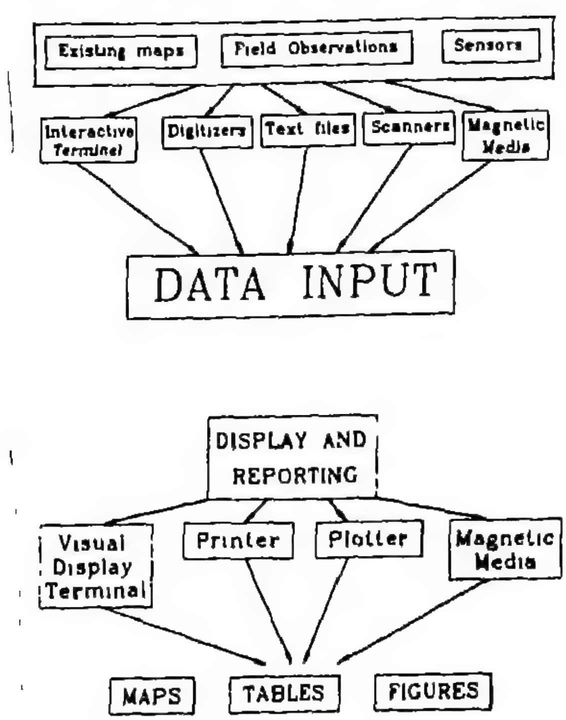


Figure 1.6: Data input and Output *(Burrough)*

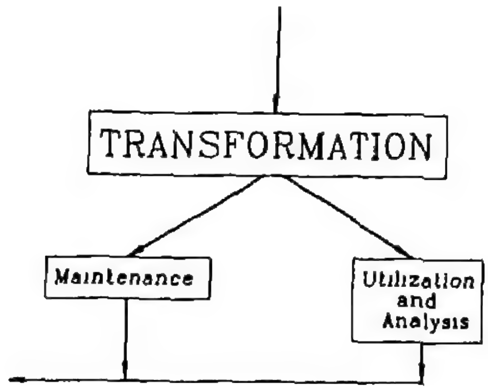


Figure 1.7. Data Transformation *(Burrough)*

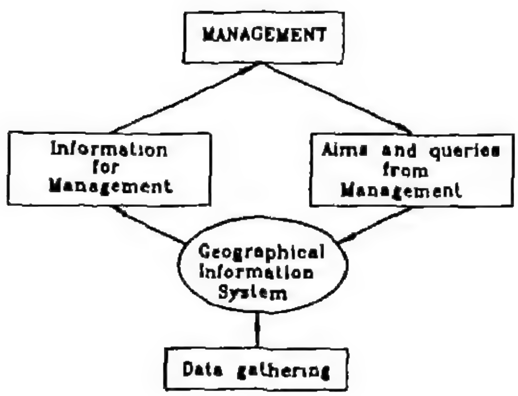


Figure 1.8: Organizational aspect of a GIS *(Burrough)*

The five technical sub-systems of GIS govern the way in which geographical information can be processed but they do not of themselves guarantee that any particular GIS needs to be placed in an appropriate organizational context as in Fig.1 8.

## 1.6 Capabilities of G.I.S. The four Ms:

Ones understanding of the planet has always been limited by the lack of information, as well as lack of wisdom and knowledge. For things too small to see, one has developed microscopes that can image down the molecular level.At the other end of the continuum for things that are (in very real sense) too large to see, one has geostation-

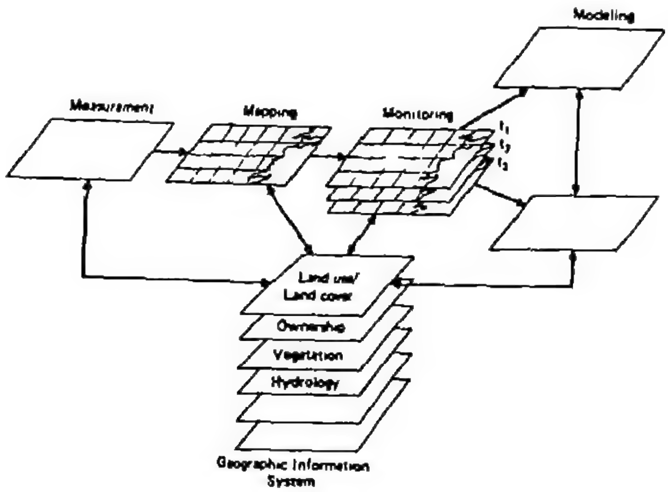


Figure 1 9. The four M's in a GIS*(Burrough)*

ary satellites that can take an image of an entire hemisphere Geographic Information Systems are a means of integrating spatial data acquired at different scales and times and in different formats. Basically urban planners,scientists, resources managers and others who use geographical information, work in several main areas. They observe and measure environmental parameters They develop maps which portray characteristics of the earth They monitor changes in human surroundings in space and time In addition they model alternatives of actions and processes operating in the environment These, then, are the four Ms: *Measurement, Monitoring, Modeling and Mapping*(Fig.1.9). These key activities can be enhanced through the use of information system technologies and in particular , through the use of a GIS.

## 1.7 Different types of G.I.S.

As mentioned above a GIS can be described as an information processing computer system that handles and analyses internally referenced spatial and non spatial data. Primary GIS operations are: e.g. thematic mapping, area and distance measurement, and spatial overlay. Sequences of primary GIS operations can be linked by the so called compound GIS operations for spatial analysis purposes. Fig1.10 illustrates some GIS features and outputs

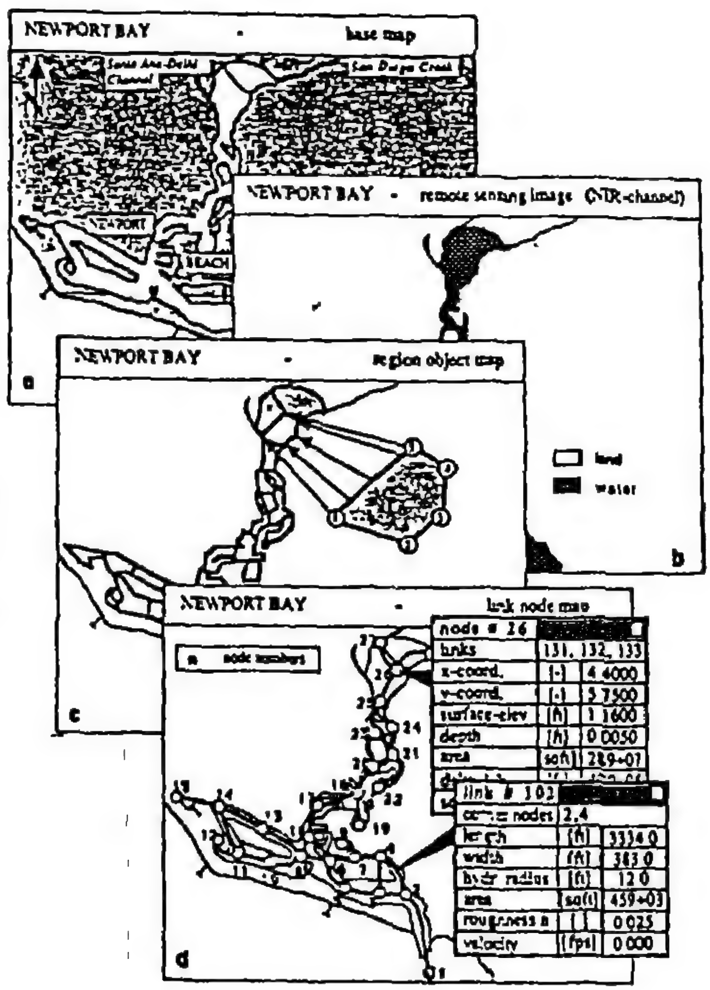


Figure 1.10: Examples of GIS data representation and object manipulation *(Burrough)*

There are two different types of GIS :

- Raster based GIS
- Vector based GIS

In a raster GIS data are stored and manipulated as picture elements(pixels) of regular two-dimensional matrices (digital images, bitmaps), stacks of multiple map layers are used to provide multivariate data representation of a region These GIS versions strongly support the representation of pictorial information such as multispectral digital images from remote sensing systems(Fig 1 10) as well as the implementation of digital image processing operations(e.g density slicing, spatial filtering, multispectral analysis). Therefore, many commercially available raster GIS are offered with options to incorporate digital image processing modules

A vector GIS generally features relational database management, object oriented data representation as vector graphics(nodes,line segments and polygons Fig 1.10 and numerous object oriented search and analysis operations (e g Boolean query,geometry analysis and measurement functions, topology analysis). In addition to area covering spatial information, vector based GIS can handle non spatial textural, temporal and tabular information The linkage of GIS and a simulation model is well supported by object oriented data representation(Fig 1 10d Arnold and Orlob, 1988) Advanced commercially available vector GIS packages(ARC/INFO) consist of four main components: the dialog module(interactive user interfaces), the relational database management system, the data analysis and manipulation module and the data display module. A comparison of both raster and vector methods are given in Tab.1.1.

## 1.8 Objective of the study

The objective of the study is to implement additional components of already implemented (partly) GRASS4.1, a GIS software GRASS4.1 in the Sun-SPARC LX workstation of Department of Civil Engineering, I.I.T Kanpur, to test the XGRASS4.1, an interactive version of GRASS4.1(GUI) in the same system, to illustrate it's capabilities by creating the hydrologic data base for the Ganga River Basin between Kanpur

| RASTER | VECTOR |
|---|---|
| *ADVANTAGES* | |
| 1)Simple Structure<br>2)Easy Overlaying<br>3)efficient for high spatial variability | 1)more "compact" structure<br>2) efficient topology encoding<br>3)better suited for graphics (eg hand-drawn maps) |
| *DISADVANTAGES* | |
| 1)Less compact(if not compressed)<br>2)topology more difficult<br>3)Jaggedness in output graphics is seen unless files are very large | 1) More complex structure<br>2) overlaying more difficult<br>3)Inefficient for high spatial variability<br>4) not effective for ehancement of digital images |

Table 1 1 **Comparision between Raster and Vector Methods**

and Allahabad and utilizing this data base for the ground water balance study of the area in both the monsoon and nonmonsoon seasons.

## 1.9 Scope of the Study

This study is not designed to develop procedures and software, but to utilize the existing software efficiently. The purpose of the study is to address the development of a GIS focusing the role of automated data processing in improving the effectiveness and efficiency of data management and data analysis using the available data for the study region

## 1.10 Significance of the Study

In the past, relevant data have been available from a variety of map sources. Though visually accessible, these map sources do not permit easy comparisons with site data

and most importantly, they do not permit the essential considerations of two or more data sources. A variety of computerized systems are now available that have these multivariate capabilities to deal with complex spatial data These GIS are conceptual equivalents of other computerized database management systems in that they permit a generalized automated structure for the entry, storage and retrieval of geographic data Though similar to other database management systems, they have the added complications presented by the spatial component of the data and its substantial size. A final difference is that GIS requires substantial commitments to data gathering in order to obtain information on the geographical characteristics of a particular area

Certainly a technology is not a panacea for all ills. It is hoped that the effective and integrated database management GIS technology, remote sensed imagery and appropriate predicative modeling can enhance management of resources

## 1.11 Organization of the study

The study is reported in following sequences:

- Introduction of GIS, objective, scope, significance and organisation of the study are discussed in Chapter 1.
- Description of the GIS(GRASS) is discussed in Chapter 2.
- Development of a spatial database is discussed in Chapter 3
- GIS features of GRASS, extraction of rainfall contours (for both monsoon and non monsoon seasons) as well as ground water table contours( both for pre-monsoon and post-monsoon) ,average rainfall using Theissen polygons, and database creation for different characteristics of irrigated areas in the study region are discussed in Chapter 4.
- Ground water balance for the two seasons is presented in Chapter 5.
- Summary, conclusions and suggestions for further study are presented in Chapter 6.

# Chapter 2

# Geographical Resources Analysis Support System

## 2.1 Background

The Geographical Resources Analysis Support System (GRASS) is a microcomputer based image processing and Geographic Information System(G.I.S.) used to develop, manipulate, analyze and display geographical data sets. Initially developed by researchers at USACERL's Environmental Division for environmental planners at military installations, GRASS is now used by a variety of public and private agencies and individuals to access environmental impacts, evaluate site suitability, detect change, manage resources and model the effects of environmental phenomenon across a landscape.

## 2.2 Definition of GRASS

Different G.I.S have different objectives,abilities, operating environments and scope. No single system does every thing. GRASS can be briefly defined by noting that it is.

**A Geographical Information System(G.I.S.) -**

It is not a word processor, a statistical system, a data base management system, or an automated mapping-facility management system It is possible to interface GRASS to such systems however

**A Program that accommodates raster and vector data format -**

Both raster and vector data formats are accommodated (to different extents) in GRASS Vector data are used in GRASS for digitizing and the graphic overlay of data All data analysis is done on raster data, and GRASS is therefore commonly refered to as a raster based system GRASS contains conversion programs to translate vector data into a raster format and vice-versa.

**A Set of tools**

When arranged with other systems, GRASS can be employed to successfully manage land resources

**A data input-output system**

GRASS is capable of data digitizing, data read-in and data read-out conversions, image processing, data analysis and data presentation GRASS continues to grow, and to provide more sophisticated utilities Cooperative efforts continue to be needed to coordinate the use of GRASS with the system, technologies, personnel, and regulations already involved in the planning process

## 2.3 Data and Capabilities

The way in which computer data is organized defines the potential for its use Geographic data can be stored in two basic formats · raster(grid cell), and vector (arc-node) Image analysis systems typically use raster data, while computer aided design (CAD) packages typically use vector data. GRASS uses both data formats.

Maps which contain distinct linear features such as roads and streams etc or distinct real features such as country boundaries, training areas, soils, polygons, etc are input to GRASS in vector format. These features are defined and stored as a series of two dimensional coordinate pairs(points).this vector data is then converted into raster format, since analysis programs in GRASS work on raster data.

GRASS uses the raster format for the processing of image and geographic data In a raster format the landscape is divided like a checkor board into a regular rectangular parcels of land attached to each parcel are identifying attributes specifying(for example) the particular parcels soil type, land cover, land use, vegetation, geology, slope, elevation,etc

GRASS, at release of version 4 1, consisted of nearly 250 different computer programs which the user can run directly through keyboard commands or indirectly through menus and other programs. A detailed list of commands are provided in Appendix These capabilities can be placed in following categories.

- Geographic Analysis
- Image Processing
- Map Display
- Data input

### 2.3.1 Geographic Analysis

Grass provides several capabilities for map analysis and overlay These include

- Analysis of site data
- Analysis of vector data
- analysis of raster data
- 2-D and 3-D manipulations
- Single cell map reporting functions
- Multi-Cell coincidence tabulations and comparisons
- Neighborhood Analysis and filters
- regional analysis
- Proximity analysis

- Boolean overlay functions
- Terrain analysis

It is this capability of bringing data derived from satellite imagery, paper maps, and other computers(e.g. elevation data) together as input to some land use questions that perhaps best defines a G I.S. Maps originally at different scales and resolutions can all provide data which can be considered in some analysis

### 2.3.2 Image Processing

Aerial images are important data sources for a G I S. They come in the form of satellite images and high altitude photography

Raw images contain tremendous amount of information GRASS image processing tools provide two primary functions necessary to prepare data for inclusion in a geographic information system.

### 2.3.3 Map display

Geographic and image processing generally require that the operator have a significant amount of training to ensure useful output. Hence, these tools are not often of interest of the GRASS novice. The most attractive and useful tools for immediate use are image display capabilities. One set(the d tools)allows the user to manipulate the display of data on the computer monitor, while the other set (the p tools) enables to generate landscape images and maps on paper.

### 2.3.4 Data input

Perhaps the most important components in a G I S. are those that are used to capture the data GRASS data is derived from paper maps, satellites and other computers A powerful array of programs for reading magnetic tapes, manipulating raw data into a form usable with GRASS, and extracting information, allows for the production of quality data. The GRASS end users will likely become very familiar with digitizing

utilities The process of entering mapped data into computer must be understood at every GRASS installation It provides the user who depends on the data with a means of keeping the data current

GRASS also provides an array of programs which will allow the user to read data from other sources Common sources include the Digital Line Graph(DLG) and Digital Elevation Model(DEM) provided by U.S. Geological Survey and the Digital Terrain Elevation Data(DTED) provided by Defense Mapping Agency(DMA). Because data development is the most expensive component of establishing any G.I S., new programs are continuously under development to read and translate data originally created for other systems into a form usable by GRASS.

## 2.4 XGRASS4.1

XGRASS4 1 is a Graphical User Interface for GRASS4 1 and it offers the user, a facility with which he can access the entire GRASS4 1 interactively. This software also has a GRASS shell through which one can use the grass commands also

## 2.5 Portability of GRASS

GRASS development has been accomplished on a variety of UNIX machines written primarily in C language. It also makes strong use of UNIX system commands. UNIX is available on PCs, workstations, minis,mainframe and supercomputers, making GRASS relatively portable.

## 2.6 Garden Concept

The new level in the GRASS hierarchy has been dubbed the "GARDEN" concept Just one can put together many salads using items in vegetable garden, it is possible to pick and choose from a huge assortment of computer programs in the analysis of data GRASS provides only some of the items to choose from, the others are the standard programs provided with the operating system and may also include other

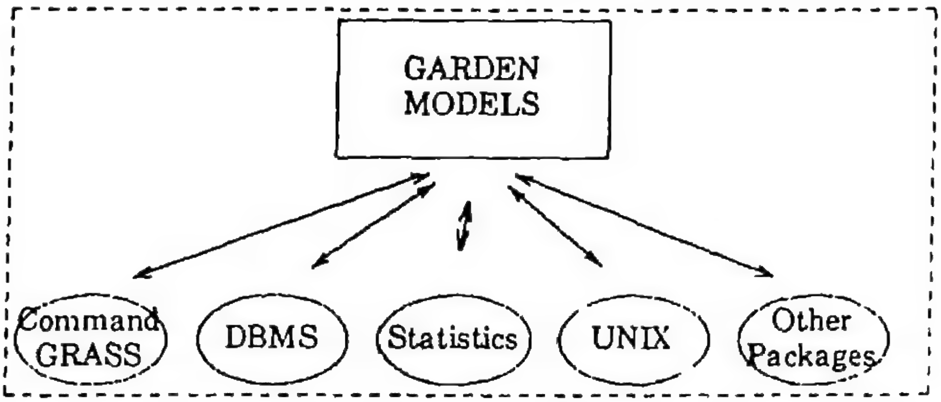


Figure 2.1. Garden concept in GRASS*(Wasterlet)*

proprietary and non-proprietary software acquired to help the user. The computer garden provides limitless opportunities for combining the computer fruits While one mix GRASS with a Database management system (DBMS) and a report writer to assist environmental managers to keep tracks of oil spilling sites, another would mix GRASS with statistics package, a voice recognition system, a natural language interface and a DBMS to allow voice query of a forest management system(Fig 2.1) At garden level GRASS can remain a solid package of G I S. programs which provides the horsepower to ever changing series of user interface and a growing array of computer programs

# Chapter 3

# Development of a Spatial Data base

## 3.1 General

G I S database development using GRASS primarily in volves planning, building and maintenance of geographic data sets It can broken down into four stages. Planning, Data collection and map preparation, Installation of data into GRASS, and augmenting and altering the existing data set. Both GRASS4 1 and XGRASS4.1 were used in the following steps for the study

## 3.2 Planning

A database is a collection of map layers on various themes for the same geographic location. A judicious decision is to be made regarding the selection of the layers of the database. This is followed by the spatial resolution which is needed for the map layer. A determination is then made as to which of the desired map layers are available in digital or nondigital formats at desired level of detail Finally, for each map layer, the number of category types,(what level of detail will be represented) is decided upon All of these decisions will depend on the applications for which the map layers are to be used.

Map layer preparation and input to G I S. can be quite costly These map layers necessary for G.I S. applications should be selected on a priority basis before the data are acquired (while some map layers like basin boundary, hydrography and soils are fairly standard, several additional map layers can be derived from one or more original layers). Careful planning coupled with technical know how and good understanding of the concepts, however decrease the data development cost to a significant extent

### 3.2.1 Map scale and map layer resolution :

Raster map layer data are stored in a grid, made up of tiny rectangles(cells) each cell in a grid represents an area on the earth which they represent, is represented by a resolution choosen for that map layer A map layer which has North-South and East-West resolution of 50m, for example is a 50m*50m square on earth. Since larger scale map contains more information for a given place on the earth than does a smaller scale map, it is appropriate to choose a corresponding cell size which represents a smaller piece of earth( in greater detail) for a larger scale map, and vice versa The resolution used is reported in Tab 3.1.

Resolution is expressed in a counter-intuitive way High resolution denotes greater detail, but is expressed by small numbers. Conversely, low resolution denotes low level of detail, but is expressed by large numbers. For example , 10m resolution data is of higher resolution than 100m resolution data.10m resolution data is capable of showing 100 times as much detail as is shown by 100m resolution data.

### 3.2.2 Cartography and digitization:

The presentation of map for digitizing, and digitizing itself are very time consuming procedures that require careful attention to details.Utmost care need to be taken for generating accurate maps Great deal of care and very sincere effort when put to digitizing process can bring out accurate maps which would be further used for analysis.Besides having extensive hands on computer experience, one should also be able to read data types, georeference satellite imageries, and exchange data between systems.

Cartography and digitizing task includes digitizing new or updated map informa-

| RASTER MAP CATEGORY REPORT | |
|---|---|
| LOCATION: spearfish | Wed Apr 12 09 51 24 1995 |

| UTM coordinates | | |
|---|---|---|
| REGION | north· 2987756.92 | east· 600898.8994 |
| | south 2765089 799 | west 298182 304 |
| | res. 99.98523619 | ıes. 100 00548246 |

| REGION CHARACTERISTICS | | | |
|---|---|---|---|
| REGION | 2987756.92 N | 600898 90 E | ZONE 42 |
| | 2765089.80 S | 298182.30 W | |

| Longitude Latıtude Details | |
|---|---|
| 26.59:58.238147N | 27 00 37.898189N |
| 83:02.02.996629W | 79.58 58 164221W |
| 24.59:23.706679N | 24.59:59 999907N |
| 82:59:59 412421W | 80:00.00.000003W |

| Scale Details |
|---|
| at northern edge 1 arc second longitude = 99207.680457 meters |
| at southern edge 1 arc second longitude = 100911 021934 meters |
| at western edge 1 arc second latitude = 110802.149268 meters |
| at eastern edge 1 arc second latitude = 110750 608030 meters |

Table 3.1: **Details of Coordinates and Resolutions**

tion, Reading data from tapes, archiving and retrieving data, documenting procedures used to create/revise data layer, and maintaining records of data updates

## 3.3 Data collection and Map preparation

### 3.3.1 Study area

The maps for Ganga river basin were obtained from the Uttar Pradesh Irrigation Department They are the xerox copies of the original maps. These maps are first studied carefully to develop the general understanding of the area. The important maps which could be used as a source for the derivation of some other related maps were selected for the analysis.

The area to be studied is the reach of River Ganga between Kanpur and Allahabad Since it is desirable that the boundaries of the area are well defined in terms of the hydraulic behaviour, it is proposed to have as the upper(Northern) and lower(Southern) boundaries major canals on either side of River Ganges,viz.,Purwa branch and Allahabad branch in the north, and West Allahabad branch, Fatehpur branch and Sasur Khaderi river in the south; at the west gradient or head control boundary defined by the hydrographic stations and at the east by the confluence of the rivers Ganga and Yamuna(Fig 3.1). In order that the boundary conditions are well defined in the model, data are required for some area around also The study area and the region of data requirements are shown in Fig 3 1

The area is located between 25 15 and 25 45 N Latitude and 80 and 82 E Longitude.It is irrigated by the Lower Ganges Canal(LGC) and the Ram Ganga Pariyojana in the Ganga Yamuna Doab and fairly extensively in the area to the north of River Ganga by Sarda Sahayak Pariyojana.

### 3.3.2 Rainfall

The normal rainfall in the area varies from a maximum of 1000mm near Allahabad to around 800mm at Unnao. The coefficient of variation is around 30occurs in the monsoon season from the middle of June to September with the maximum in July-

| Raingauge Stations |
|---|
| Kanpur |
| Chakeri |
| Unnao |
| Hasanganj |
| Purwa |
| Ghatampur |
| Khajuha |
| Fatehpur |
| Safipur |
| Rae-bareli |
| Khaga |
| Salon |
| Sirathu |
| Manjanpur |
| Kunda |
| Bamrauli |
| Allahabad |
| Phulpur |
| Pratapgarh |

Table 3.2: Rain Gauging stations in the Study Region

August.

The details of rainfall stations and the monthly rainfall data for the period of 1979 to 1982 are collected from the U P Irrigation Board and are used for the database creation and subsequent analysis.

The list of rainfall stations in the study area is presented in Table 3.2 .

### 3.3.3 Ground Water

Water table levels constitute one of the most important basic data sets for the creation and analysis of a database. Adequate ground water level data concerning shallow water tabels(premonsoon and postmonsoon) are collected for different districts in the study area.

## 3.4 Desk top Scanning

### 3.4.1 Introduction

Over the past 20 years, a great deal of attention has focused on development of techniques to alleviate the labor intensive process of manual cartographic digitizing as tradition ally accomplished using tables and cursors Advances in digital equipment for data entry, in computer processing speeds and in memory addressing have increased the options previously available in digitization. Although manual tables are still most widely used, the raster scanner is rapidly becoming a viable alternative A scanner takes a very different approach to capture of digital data from analog originals than does the digitizing table. In raster scanning, an original is captured in its entirety in a few minutes or less. A map becomes a massive matrix of reflectivity values, each a generalization of a small portion of the original.

Scanners reduce the amount of time required to produce computer readable file and are economically advantageous in systems requiring at least moderate levels of data entry. Throughput *time savings from scanning are significantly affected* by the amount of map preprocessing, and data postprocessing (format conversion [vectorization] and feature labeling) required to create a use able data file.

In the recent times, scanning, like many electronic technologies, has declined greatly in price, but large format production scanning is still expensive and complex enough that manual digitization remains the prevalent digitizing technique.

### 3.4.2 Raster scanning of cartographic products :

The capabilities of a scanner are described through specifications of spatial and radiometric resolutions. Spatial resolution refers to size of individual picture elements(pixels) and may be defined by either rows and columns of an output matrix or by number of "dots per inch"(*dpi*).either measurement can be converted by the scale of the map original to ground resolution For example if scanning a 1:24,000 scale map at 200 dpi the pixel size is 10 feet

Radiometric resolution describes the range of values the device can discriminate for each pixel Radiometric resolutions typically range from two levels of brightness(binary) to 256 levels of brightness(*256 grey level*).

### 3.4.3 Desk top Scanning

"Desk top publishing's rapid ascention from an eccentric endeavor to a bonafide software application has carried scanning equipment to the fore" *(O'Melly, 1988, p 208)* Today's flat bed scanners are affordable to a wide audience and offer an impressive array of hardware and software features including:

- User selectable binary and grey/color radiometric resolution(up to 256 levels)
- User selectable spatial resolution more than 600 dpi.
- Interactive image sub setting to allow the user to scan a selected portion of the original.
- Scanning of the original documents up to 8.5 by 14.0 inches and larger.

### 3.4.4 About the scanner and output files

A Hewlett-Packard 9090a Scan jet desk top scanner with associated "Scanning Gallery Plus 5.0" software was used to scan the photocopies of original maps.

The software provided with the scanner supports digitization of documents in a two phase procedure. A preview scan of the entire surface is presented in same form

on the computer screen. The user then subsets the image from the screen preview, and the final scan recovers data only from that portion of the scanning surface. A wide variety of options is available for the final scan, and a Tag Image File (*TIFF*) is written to a data storage device.

Though there is no single standard format, tag image file contains header followed by pixel data. Values in the header reveal number of rows and columns in the image, and the data are in different format for binary and for grey scale files As with many of the raster formats TIFF files can be extremely large A 256 grey scale radiometric file containing 672 rows and 1167 columns requires approximately 784KB of storage if data are packed at 8 bits per pixel If translated into ASCII format ( img format) the file requires approximately 3186KB of memory, more than four times that of a TIFF file. However, it is easiest to extract data from the TIFF file directly

### 3.4.5 Spatial and Radiometric resolutions

Scanning a map at lower resolution (dpi) results in significantly shorter processing times as many post processing algorithms progressively thin the lines through peeling away edges until lines of a single pixel width result. The opposing view is that a certain minimum dpi is required to maintain the connectivity of line work and to preserve fine detail Trials determined that 150 dpi is the optimal spatial resolution to define all the concerned regions on the maps, and that 256 grey scale is much more effective than the binary scale for resolving variations among the map colors. Hence a spatial resolution of 150 dpi and a radiometric resolution of 256 grey level has been adopted for scanning different maps.

## 3.5 Digitization of a Vector map

### 3.5.1 Input of spatial data

Most often vector maps defining the linear features of the region are required for data analysis and modeling. The process in which these maps are generated is known as digitization. During digitization all features are recorded as a series of X and Y-coordinates, using a digitizer. In present study the screen itself is a digitizing table

and the GRASS binary raster layer serves as the map The GRASS program *v.digit*, a highly interactive digitization and map development program is used for vector digitizing,editing,and labeling.The raster map layer is displayed on screen as a back drop cell map using the customization mode of the *v digit* software and using the menu based features of the program , details of the linear features of the actual map are digitized by careful movement and appropriate clicking of the mouse

**Editing :**

Since digitizing is a tedious operation, mistakes will inevitably occur. Editing facilities are therefore necessary.Common errors occurring during the process of map digitizing include:

- Failure to snap lines together at nodes
- Over- and under shooting of lines
- Omission of lines or points.
- Double recording of lines or points
- Incorrect feature coding
- Incorrect location of features

**Attribute entry :**

Feature labels are entered via keyboard within a spatial menu area reserved, immediately after a line or an area or a site is digitized.

## 3.6 Input of Non-spatial data

Input of non-spatial data for a map in GRASS is done by editing the corresponding vector digital file in dig-att directory And after editing this file it is linked with the spatial data. This is done by using the utility *v.support.*

## 3.7 Vector to raster conversion

Since GRASS is a raster based geographical information system the original digitized vector data is converted before the analysis is performed The process of vector to raster conversion involves the following steps

The program *v.to.rast* is a conversion utility, which converts vector data to raster data

## 3.8 Data compression

Since many of the cells contain the same value as neigh bouring cells, there is considerable redundancy. Hence significant reductions in size of the data files is achieved by using the data compression option of the program *r support*

The list of maps which are digitized and converted into raster format is shown in the Table 3 3.

| S No. | Map Name | Title |
|---|---|---|
| 1. | ka.tsp | Study Region |
| 2 | ka tsp poly | Theissen Polygons |
| 3. | r sites | Raingage Stations |
| 4 | g sites | Ground water stations |
| 5. | pre.gw | Premonsoon groundwater table levels |
| 6 | post gw | Postmonsoon groundwater table levels |
| 7 | r m | Monsoon rainfall values |
| 8. | r.nm | Non monsoon rainfall values |
| 9. | r t | Normal rainfall values |
| 10 | dist | Districts in the region |
| 11. | ganga | River Ganga |
| 12 | canals | Different canals |
| 13 | cancom | Canal command area |
| 14 | india | Map of India |
| 15 | up | Map of Uttar Pradesh |
| 16. | blocks | Irrigation Blocks |
| 17. | bl.tia | Total Irrigated Area(Block wise) |
| 18 | bl.1 | Net Irrigated Area(blockwise) |
| 19. | bl.2 | Canal Irrigated Area(blockwise) |
| 20. | bl 3 | Paddy Irrigated area(blockwise) |
| 21. | bl.4 | Sugarcane Irrigated Area(blockwise) |
| 22. | bl.5 | Wheat Irrigated Area(blockwise) |

Table 3.3: List of maps prepared through *v.to rast*


KANPUR
UNNAO
FATEHPUR
RAEBARELI
PRATAP GARH
ALLAHABAD
SAI RIVER
FATEHPUR BR
UNNAO BR
KAMPUR
SALON
BIHAR
KAURIHAR
MANJANPUR
NEVADA
SARASWAN
KANAILI
MAU-AIMA
SANGIPUR
LAKHANPUR
MANDHATTA
HASWA
JAGATPUR
UNCHAHAR
ASOTHAR
KHAJUHA
AMOLI
VIJAIPUR
KARARI
KUNDA
BHITARGAON
MAURAWAN
PURWA
NAWABGANJ
DALMAU

# Chapter 4

# Data Analysis and Map Display

## 4.1 Introduction

The most important characteristic of Geographical Information System is the provision of capabilities for spatial analysis functions These functions use the spatial and non-spatial attributes in the database to answer questions about the real world

The database in a G.I S. can be used to simulate certain aspects of reality A model may be represented in words, in mathematical equations or as a set of spatial relations displayed as a map

## 4.2 Analysis functions

The objective of data analysis is to extract or query useful information to satisfy the requirements or objectives of decision makers at all levels of detail. An important use of the analysis is the possibility of predicting what will happen in another location or at another point in time This ability provides the possibility to select the best possible alternative design.

The range of analysis procedures have been subdivided into following categories.

- Retrieval

- Reclassification
- Measurement
- Overlay
- Search functions
- Topographic functions
- Interpolation functions
- Other functions

### 4.2.1 Retrieval operations

Retrieval operations on the spatial and non spatial data involve the selective search and manipulation, and output of data without the need to modify the geographical location of features or to create new special entities.

Retrieval operations include.

- Retrieval of data using geometric coordinates
- Retrieval of data using symbolic specifications
- Retrieval of data using conditional and logical statements.

There are numerous retrieval utilities available in GRASS and almost all the utilities are used to in the analysis of maps and generation of reports. Some of these utilities are totally interactive(needing a mouse) and some are non-interactive The list of these utilities and their brief details are tabulated in Table 4.1.

For example the utility *d profile* shows the profile of a particular variable along the user selected section on the map The utility *d histogram* shows the bar/pie charts of the category values.

For example, monsoon rainfall surface (interpolated from the program *r.surf idw* and named *r m.surf*) and four sections on this map layer are used as inputs to the utility *d profile*. the results showing the rainfall along the four sections are shown in

| program | Discription |
|---|---|
| d geodesic | Displays a geodesic line, tracing the shortest distance between two geographic points along a great circle, in a longitude/latitude data set |
| d histogram | Displays a histogram in the form of a pie or bar chart for a user-specified raster file |
| d.legend | Displays a legend for a raster map layer in the active frame on the graphics monitor |
| d rhumbline | Displays the rhumbline joining two user-specified points, in the active frame on the user's graphics monitor |
| d what rast | Allows the user to interactively query the category contents of multiple raster map layers at user-specified locations within the current geographic region |
| d where | Identifies the geographic coordinates associated with point locations in the active frame on the graphics monitor |
| d rast.num | Overlays cell category values on a raster map layer displayed to the graphics monitor |
| r.cats | Prints category values and labels associated with user-specified raster map layers |
| r coin | Tabulates the mutual occurrence (coincidence) of categories for two raster map layers. |

| program | Discription |
|---|---|
| r.covar | Outputs a covariance/correlation matrix for user-specified raster map layer(s). |
| r.describe | Prints terse list of category values found in a raster map layer. |
| r.info | Outputs basic information about a user-specified raster map layer |
| r.report | Reports statistics for raster map layers |
| r.stats | Generates area statistics for raster map layers |
| r.volume | Calculates the volume of data "clumps", and produces a GRASS sitelists file containing the calculated centroids of these clumps. |
| s.db.rim | RIM data base management/query interface for GRASS sites data. |
| r.average | Finds the average of values in a cover map within areas assigned the same category value in a user-specified base map. |
| d.measure | Measures the lengths and areas of features drawn by the user in the active display frame on the graphics monitor. |
| d.display | Displays profiles of a user-specified raster map layer. |

Table 4.1: Retrieval Operations in GRASS4.1

| program | discription |
|---|---|
| r buffer | Creates a raster map layer showing buffer zones surrounding cells that contain non-zero category values |
| r cross | Creates a cross product of the category values from multiple raster map layers |
| r reclass | Creates a new map layer whose category values are based upon the user's reclassification of categories in an existing raster map layer |
| r combine | Allows category values from several raster map layers to be combined |

Table 4.2 Reclassification Utilities in GRASS4.1

the Fig 4 10. The block wise irrigated areas are given in map layer *bl tia* The utility *d histogram* is used to present the irrigated areas in each block as a barchart (Fig 4 12)

### 4.2.2 Reclassification procedures

Reclassification procedures involve operations that reassign thematic values to the categories of an existing map as a function of the initial value,the position, size or shape of the spatial configuration associated with each category, for instance a rainfall surface map, reclassified into a map of irrigation blocks involves the process of looking at the attribute for a single data layer and assigning an additional attribute, the new class name.

Reclassification can also be performed in multiple data layers as part of an overlay operation. For example, a sugar cane irrigated area, a paddy irrigated area and a wheat irrigated area map can be presented as different data layers.

The reclassification utilities present for the analysis in GRASS4 1 and their brief, is tabulated in Table 4 2

*r cross* and *r combine* are the reclassification utilities which were used in the present work. The utility *r.combine* helps us to combine different maplayers and also to overlay them The program *r.cross* generates the cross product of the values

| Average Monsoon rainfall (as given by program) | |
|---|---|
| Station | Rainfall(mm) |
| Kanpur | 740.4337156575 |
| Chakeri | 755 9480371859 |
| Unnao | 737 1166480962 |
| Hasanganj | 748 8391180073 |
| Purwa | 765 0584144645 |
| Ghatampur | 752 4656925032 |
| Khajuha | 783.5278414453 |
| Fatehpur | 787.972397369 |
| Safipur | 810.6612679858 |
| Rae-bareli | 822.0424881703 |
| Khaga | 828.8577208558 |
| Salon | 845.5810441954 |
| Sirathu | 846.1989276627 |
| Manjanpur | 817 8595643596 |
| Kunda | 853.5689632589 |
| Bamrauli | 853.2688271784 |
| Allahabad | 845.6907494936 |
| Phulpur | 865.8317571776 |
| Pratapgarh | 868.8675237563 |

Table 4.3: Average monsoon rainfall in different zones(Report from *r.cross*)

| program | discription |
|---|---|
| d geodesic | Displays a geodesic line, tracing the shortest distance between two geographic points along a great circle, in a longitude/latitude data set |
| d.histogram | Displays a histogram in the form of a pie or bar chart for a user-specified raster file |
| r.report | Reports statistics for raster map layers |
| r.volume | Calculates the volume of data "clumps", and (optionally) produces a GRASS site-lists file containing the calculated centroids of these clumps |
| r average | Finds the average of values in a cover map within areas assigned the same category value in a user-specified base map |
| d measure | Measures the lengths and areas of features drawn by the user in the active display frame on the graphics monitor |
| v area | Measures the areas of specified regions on a vector map |

Table 4.4 Measurement functions in GRASS4.1

present in the given map layers.

### 4.2.3 Measurement functions

Measurement of spatial data involves the calculation of distances between points, lengths of lines, area and perimeter of polygons, and volumes.

There are number of utilities which perform the functions of measurement. For example the map layer *r.m.surf* is used as the upper map to calculate the average monsoon rainfalls over different districts in the study area (map layer *dist*) using the utility *r.average*. The results are tabulated in Table 4.10.

The list of measurement functions in GRASS4.1 and their brief is given in Table 4.4.

### 4.2.4 Overlay operations

Overlaying of maps result in the creation of a new map where the values assigned to every location on that map are computed as a function of independent values associated with that location on two or more existing maps Overlaying creates a new data set containing new polygons formed from the intersection of boundaries of the two or more data layers In addition of creating new polygons based on the overlay of the multiple layers, these polygons have multiple attributes,i,e.,the attributes which were given to each separate overlay before the composition occured.

Arithmetical and logical overlay are also possible in GRASS such as addition, subtraction, division, multiplication of each value in a data layer by the value corresponding to the same location in another data layer Logical overlay involves the selection of an area where a set of conditions are satisfied

The typical GRASS overlay utilities and their brief is listed in Table 4 5. The utility *r.combine* is a languauge driven overlaying utility and is used to overlay the map layers *ganga and cancover* showing the River Ganga and the canal command area respectively on the study area (map layer *ka tsp*) The report is shown in Table 4.6. The net irrigated areas in each block (map layer *bl 1*) are overlaid on the raster map showing the blocks map layer *blocks*) using the utility *r cross* The report is shown in Tables 4 7 and 4 8

### 4.2.5 Search functions

Search functions constitute one of the most commonly used neighborhood functions They determine the value of each target feature according to some characteristic in the neighborhood.

Typical search functions are the functions which determine the total, average, maximum, minimum and statistics such as mean, standard deviation etc

The typical GRASS search functions, and their brief are shown in Table 4.9. and the resultant reports are tabulated in Table4.10.

| program | discription |
|---|---|
| r combine | Allows category values from several raster map layers to be combined |
| r mapcalc | Raster map layer data calculator, performs arithmetic on raster map layers |
| r cross | Creates a new map layer whose category values are based upon the user's reclassification of categories in an existing raster map layer |
| r weight | A language driven raster map overlay program |
| r infer | Outputs a raster map layer whose category values represent the application of user-specified criteria (rules statements) to other raster map layers' category values |

Table 4 5· Overlaying Functions in GRASS4 1

| MAP · gcover in tsp | |
|---|---|
| OVERLAY 1—— | Non Canal Command Area |
| OVERLAY -2—- | Ganga/Yamuna River |
| 1—2— — | River Ganga |
| 1— —3— | Canal Command Area |

Table 4.6· Overlay of command areas and rivers

| Net irrigated area in irrigation blocks(Hectares) | |
|---|---|
| NAWABGANJ | 6898 |
| HASANGANJ | 15947 |
| MIYANGANJ | 8109 |
| SAFIPUR | 10696 |
| SIKANDARPUR | 9622 |
| KALYANPUR | 8433 |
| BIDHNOO | 12407 |
| BHITARGAON | 14391 |
| KANPUR | 11718 |
| PURKARON | 10236 |
| BICHCHIA | 17086 |
| ASOHA | 8925 |
| PURWA | 11501 |
| BIGHAPUR | 5090 |
| SARSAUL | 14090 |
| HILAULI | 7620 |
| KHIRON | 9366 |
| SUMERPUR | 9000 |
| DEOMAI | 10469 |
| KHAJUHA | 11707 |
| SARENI | 9878 |
| LALGANJ | 7672 |
| DALMAU | 12381 |
| SATAON | 10709 |
| TALYANI | 11667 |
| HASWA | 11661 |
| BITHURA | 11882 |
| RAHI | 13993 |
| JAGATPUR | 12413 |
| NATHGARH | 6800 |
| VIJAIPUR | 6954 |
| DHATA | 9128 |

Table 4.7: Report from *r.cross*

| | |
|---|---|
| SARASWAN | 8156 |
| UNCHAHAR | 12074 |
| SALON | 14368 |
| KALAKANKAR | 9347 |
| KARA | 5266 |
| RAMPUR | 12744 |
| BABAGANJ | 10876 |
| KUNDA | 9957 |
| SIRATHU | 7183 |
| BIHAR | 10945 |
| ARASWAN | 4400 |
| MANJANPUR | 4558 |
| NEWADA | 4906 |
| KAURIHAR | 5564 |
| CHAIL | 4539 |
| KAURIHAR | 5564 |
| HOLAGARH | 7865 |
| MAU-AIMA | 9194 |

Table 4.8: Net Irrigated Area( in Hectares)

| program | discripton |
|---|---|
| r average | Finds the average of values in the cover map within areas as signed the same category values in base map |
| r watershed4.0 | Watershed basin analysis program |
| r basins fill | Generates a raster map layer showing watershed subbasins |
| r cost | calculates the cost to go to one point to another. |
| r drain | shows the drainage lines |
| r thin | Smoothens the raster map layer |
| r grow | Increases the category zone by one pixel |

Table 4 9: Search Functions in GRASS4.1

| MAP: Reclass of dist.1 in tsp (m.ave in tsp) | |
|---|---|
| Unnao | 759.2609763687 |
| Kanpur | 752.0110575723 |
| Rae-Bareli | 818 5627412587 |
| Fatehpur | 805.2529027288 |
| Allahabad | 841.9527644379 |
| Pratapgarh | 856 22646091 |

Table 4.10: Average monsoon rainfall over districts

| | |
|---|---|
| r surf.contour | r slope aspect |
| r cost | r.traj |
| r.volume | r.los |
| d.rast arrow | r.watershed |

Table 4 11· Topographic Functions in GRASS4.1

### 4.2.6 Topographic functions

The surface characteristics such as the slope,relief and form of an area are referred to as topography

In the present study these functions are not used, but the list of these utilities is tabulated in Table 4 11 .

### 4.2.7 Interpolation functions

Interpolation is the procedure of estimating unknown values at un sampled sites using known values of existing observations at neighborhood locations. Point based interpolation is used to estimate the values at predetermined locations using points of known locations and values. The output can be an isohyetal map The utilities *r surf.idw* and *s.surf.idw* are the programs which generate the trend surface from the available values. The quality of the interpolation results is a function of precision, accuracy, number and distribution of points used in the calculation and the manner in which the mathematical function models reality. The choice of appropriate model is , therefore crucial in order to secure reasonable results. The interpolation method used in the present study is explained below.

### 4.2.8 Inverse squared distance weighting:

One of the most often used methods of interpolating a value of a variable Z at an unvisited point x, is to compute an average value from local neighborhood. In its simplest form, for a regularly spaced data along the transect, the moving average for

a point x in the centre of symmetric window is computed as

$$\hat{Z}(x) = 1/n \; [\sum_{i=1}^{n} Z(x_i)] \tag{4 1}$$

In two dimensions, the same formula would apply, with the sites $x_i$ replaced by the coordinate vector $X_i$.

The size of window has a definite effect in the form of smoothed output Narrow windows will emphasize short range variations and broad windows will reduce short-range variations in favour of longer range effects.

As we have already noted, observations located close together tend to be more alike than observations spaced further apart. It is natural to feel that the contribution that a given sample point makes to an average interpolated value at an unvisited site should be weighted by a function of the distance between that observation and the site So we can compute a weighted moving average

$$\hat{Z}(x) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad\qquad \sum \lambda_i = 1 \tag{4 2}$$

where the weights $\lambda_i$ are given by $\phi(d(x, x_i))$.

A requirement is that $\phi(d) \rightarrow \infty$ as $d \rightarrow \infty$ , which is given by commonly used reciprocal or negative exponential functions. Perhaps the most common form of $\phi(d)$ is the inverse squared weighting

$$\hat{Z}(x) = \frac{\sum_{i=1}^{n} Z(x_i)\, d_{ij}^{-2}}{\sum_{i=1}^{n} d_{ij}^{-2}} \tag{4 3}$$

where $x_j$ are the points at which the surface is to be interpolated; usually the points lie on a regular grid

The size of the domain not only affects the average value estimated at a point, but also the amount of computer time required for interpolation.Usually the size of the domain is set to a minimum and a maximum number of data points in an effort to balance computational efficiency against precision. The number of points used may vary between 4 and 12, but is usually in the range of 6-8, particularly if the original

| | |
|---|---|
| r surf.idw | s surf idw |
| r contour | |

Table 4.12 Interpolation Functions in GRASS4 1

data lie on a regular grid, but when the data are irregularly distributed, each inter polation will be made using a window of different size, shape and orientation.

The clumping problem with irregularly spaced data is solved by giving reduced weights to those data points that are screened from the interpolation point by other points This is done by diminishing the weight given to the farther point in proportion to the cosine of angle between the data points and the interpolated point

The interpolated values at the grid points are displayed as greyscale raster maps These interpolated grid cell values can be used as an overlay in a raster data analysis

In the present study the monsoon nonmonsoon and annual rainfalls over the study area are interpolated from the rainfall values at the rain gauging stations using the two models *s surf idw* and *r surf.idw* The interpolation for the two models differ In that *s surf.idw* gave steep profiles not representative of the variation of precipitation, hence in this case *r surf idw* seems preferable The result for total annual precipitation is shown in Fig 4 4

Pre-monsoon and post-monsoon water table levels for 131 stations are available. They were used to derive the ground water table surface and contours

## 4.3 Map Display

The maps which were developed using the above mentioned procedures have been displayed on a screen using several GRASS display utilities The GRASS display tools are tabulated in Table 4 13. The list of the developed Raster, Vector and Site maps is shown in Table 4.14. The photographs of some of those maps are shown in Fig.4 1 to Fig 4 12, the details of these figures are:

- The raster map of Study Area ( Gaga River Basin between Kanpur and Allahabad is shown in Fig 4.1
- The raster map of the six districts in the study region are shown in Fig4 2
- The raster maps of canal system and the study area are overlaid and is shown as a single map layer in Fig 4.3
- The annual rainfall surface is interpolated and this surface is overlaid on the study region and is shown in Fig 4.4
- The map showing the rainfall Theissen polygons is shown in Fig 4 5
- The vector map of rainfall contours is overlaid on the study area and the resultant map layer after appropriate labelling is shown in Fig 4 6.
- The vector map of post monsoon ground water table level contours (extracted from the post monsoon ground water level interpolated surface using the utility *r contour*) is overlaid on the map representing the study area. This map is shown in Fig 4.7
- 3D view of topographical surface of the study region is shown in Fig 4 8
- 3D view of Annual rainfall distribution over the study region is shown in Fig 4.9.
- The color photo showing the capability of the utility *d profile* is shown in Fig 4.10.
- The rainfall Theissen polygons in the study area with their legends are shown in Fig 4.11 to illustrate the capability of the utility *d display*.
- The raster map of the total irrigated areas in each block and the bar chart showing the values of these areas are shown in Fig 4 12 to illustrate the capabilities of the utilities *d.histogram* and *split view sh*

| | |
|---|---|
| Raster | d display |
| | d his |
| | d rgb |
| | d.profile |
| | d 3d |
| | 3d.view sh |
| | slide.show.sh |
| Vector | d.display |
| | d vect |
| | d.vect dlg |
| Sites | d display |
| | d.points |
| | d sites |
| | d icons |
| Text | d.display |
| | d.menu |
| | d text |
| | d.label |
| | d.labels |
| | d paint labels |
| | d.legend |
| | show fonts.sh |
| Screen Graphics | d display |
| | d scale |
| | d.grid |
| | d colortable |
| | d.graph |
| | d.mapgraph |
| | d geodesic |
| | d.rhumbline |
| | d.histogram |
| | grass logo.sh |



Table 4.13 Map display functions in GRASS4.1

| Map Name | discription |
| --- | --- |
| ka tsp | Study Region |
| ka tsp poly | Theissen Polygons |
| r sites | Raingage Stations |
| g sites | Ground water stations |
| pre.gw | Premonsoon groundwater table levels |
| post gw | Postmonsoon groundwater table levels |
| r.m | Monsoon rainfall values |
| r.nm | Non monsoon rainfall values |
| r t | Normal rainfall values |
| dist | Districts in the region |
| ganga | River Ganga |
| canals | Different canals |
| cancom | Canal command area |
| india | Map of India |
| up | Map of Uttar Pradesh |
| blocks | Irrigation Blocks |
| bl.tia | Total Irrigated Area(Block wise) |
| bl.1 | Net Irrigated Area(blockwise) |
| bl.2 | Canal Irrigated Area(blockwise) |
| bl.3 | Paddy Irrigated area(blockwise) |
| bl.4 | Sugarcane Irrigated Area(blockwise) |
| bl.5 | Wheat Irrigated Area(blockwise) |
| r.sites.surf | Rainfall Surface(Total) |
| r.nm.surf | Rainfall Surface(Nonmonsoon) |
| r.m.surf | Rainfall Surface(monsoon) |
| pre.gw surf | pre mon g w table surface |
| post.gw.surf | post.mon g.w.table surface |

| Map Name | Discripton |
|---|---|
| r.sites cont | total rainfall contours |
| r.nm.cont | r f.contours (nonmonsoon) |
| r m cont | r.f contours (monsoon) |
| pre.gw cont | g w t.contours (premon) |
| post gw.cont | g.w.t contours (postmon) |
| cross.nm.surf | cross of nonmonsoon r f and polygons |
| cross m.surf | cross of monsoon r f and polygons |
| cross t.surf | cross of toal r f and polygons |
| pregw.surf | interpolated sueface of premonsoon g w.t |
| postgw surf | interpolated surface of postmonsoon g w t |
| cross tia | cross of blocks and total irrigated area |
| cross.1 | cross of blocks and net irrigated area |
| cross.2 | cross of blocks and canal irrigated area |
| cross 3 | cross of blocks and paddy irrigated area |
| cross.4 | cross of blocks and sugarcane irrigated area |
| cross.5 | cross of blocks and wheat irrigated area |
| cross 6 | cross of blocks and double irrigated area |
| cross.7 | cross of blocks and noncanal irrigated area |
| cross.8 | cross of blocks and (paddy+wheat) double irrigated area |
| cross.9 | cross of blocks and kharif canal irrigated area |
| cross 10 | cross of blocks and rabi canal irrigated area |
| cross.11 | cross of blocks and canal irrigated area(wheat only) |
| cross.12 | cross of blocks and non canal irrigsted area(wheat only) |
| cancover | overlay of cancom over ganga |
| cancover1 | overlay of cancom over canals |

| Map Name | Discription |
|---|---|
| gcover | overlay of cancover over ka |
| m ave | Average rainfall in different districts |
| nm.ave | Average nonmonsoon rainfall in different districts |
| post ave | Average postmonsoon g.w t in districts |
| pre ave | Average premonsoon g.w t in districts |
| sr m.ave | Average monsoon rainfall over the entire region |
| sr.nm ave | Average nonmonsoon rainfall over the entire study region |
| sr pre ave | Average premonsoon g w.t. over the study region |
| sr post ave | Average post monsooon g.w.t over the entire study region |
| sr t ave | Average total rainfall over the entire study region |
| t.ave | Reclass of districts |
| bl.10 | Rabi canal irrigated area |
| bl 11 | Canal irrigated area (wheat only) |
| bl.12 | Non canal irrigated area(wheat only) |
| bl.6 | Double irrigated area |
| bl 7 | Non canal irrigated area |
| bl.8 | paddy+wheat double irrigated area |
| bl.9 | Kharif canal irrigated area |

Table 4 14: List of Raster Maps in the Data base

| Vector files available in mapset tsp | | |
|---|---|---|
| 1 | dist 1 | pre.gw cont |
| 2 | dist.poly | pre.gw cont.tmp |
| 3 | gs | r m.cont |
| bl 1 | gw | r.sites |
| bl 1 tmp | gw.temp | r sites cont |
| bl.2 | ind | r sites.m |
| bl.3 | india | r sites.nm |
| bl.4 | india1 | r.sites nm cont |
| bl.5 | ka.grid | r.sites.nm cont1 |
| blk | ka m cont | raingages |
| block.area | ka mapcalc | isites.cont |
| block.tia | ka nm cont | test |
| blocks | ka sites cont | tsp.gw |
| canal | ka.tsp | tsp pregw |
| canal1 | ka.tsp.poly | tsp2 gw |
| cancom | ka tsp2 | up |
| cover | kapoly | v.patch |
| cover canal | poly 1 | veg |
| cross | post.gw | wells |
| d.cont | post.gw cont | wells1 |
| diff cont | post.gw cont.tmp | wells3 |
| dist | pre gw | |

| Site list files available in mapset tsp | | | |
|---|---|---|---|
| 1 | g.sites | r sites | up |
| 2 | gw | r.sites1 | wells |
| 3 | pregw | raingages | wells1 |
| c.sites | pregw surf.rand | rg1 | wells2 |

| 3D viewing parameters files available in mapset tsp | | |
|---|---|---|
| ka.pregwsurf.3d | kapoly.3d | pre gw.surf |
| ka.rcont.3d | kapoly.precont.3d | pregw.surf.3d |
| ka.rgsurf.3d | kapoly.rcont.3d | r.sites surf |
| ka.tsp poly | kapoly.rgsurf 3d | |

Table 4 15: List of prepared maps

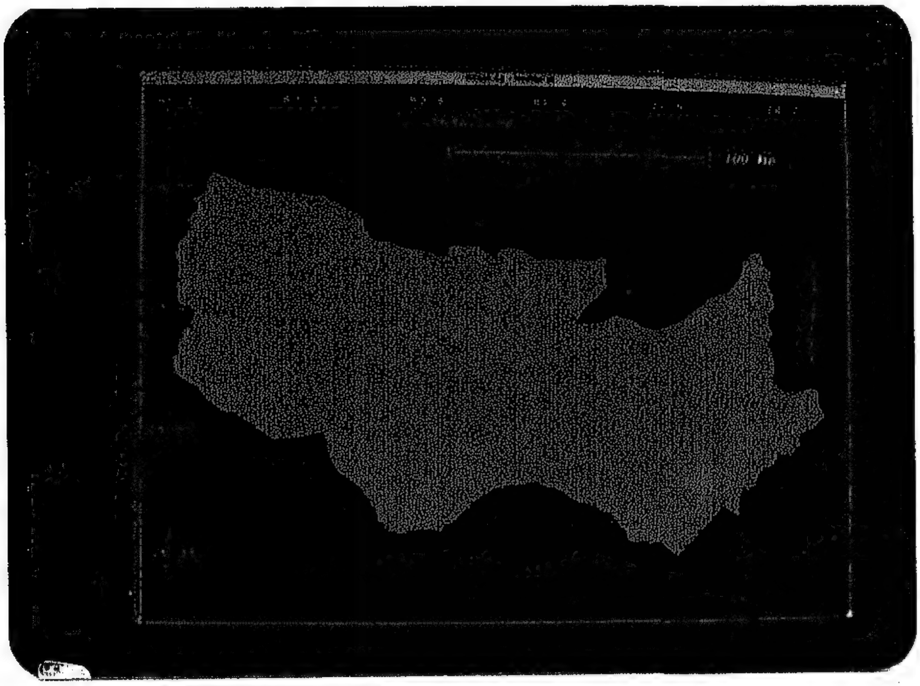

Figure 4.1: Raster Map of Study Area

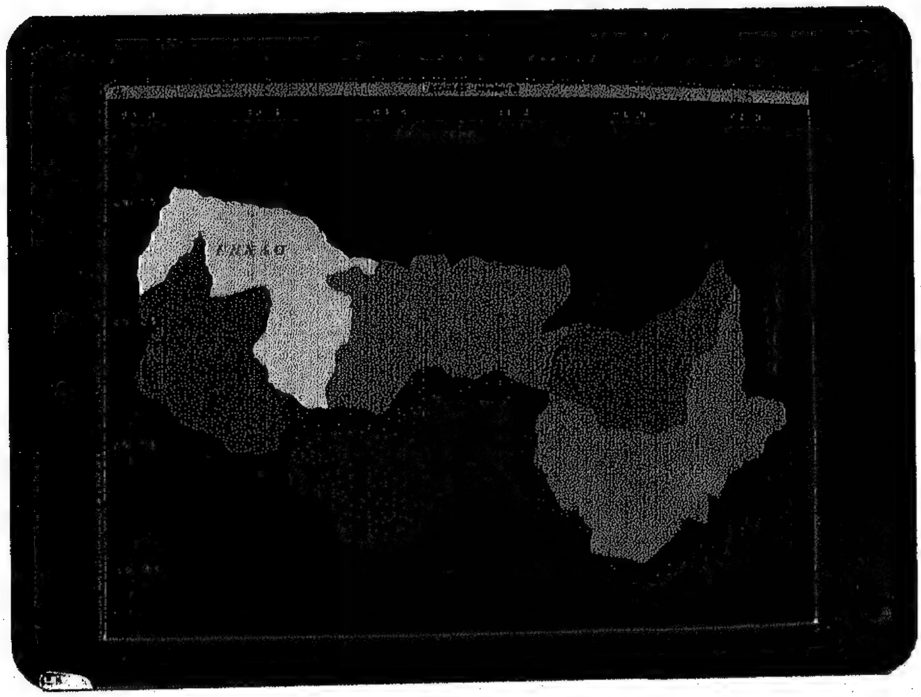

Figure 4.2: Raster Map of Districts in the study area

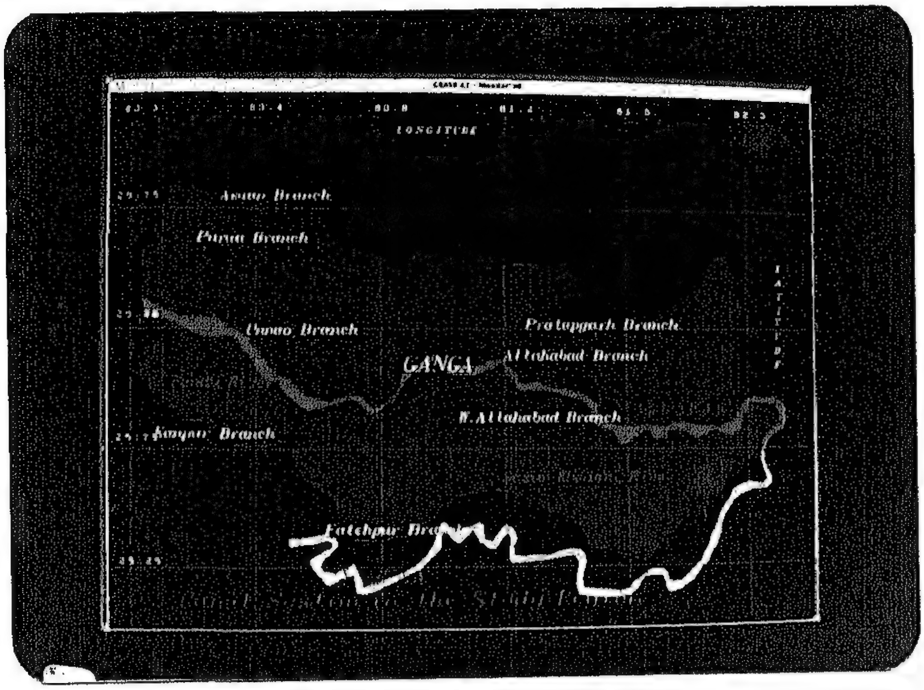


Figure 4.3: Raster Map of Different canal systems

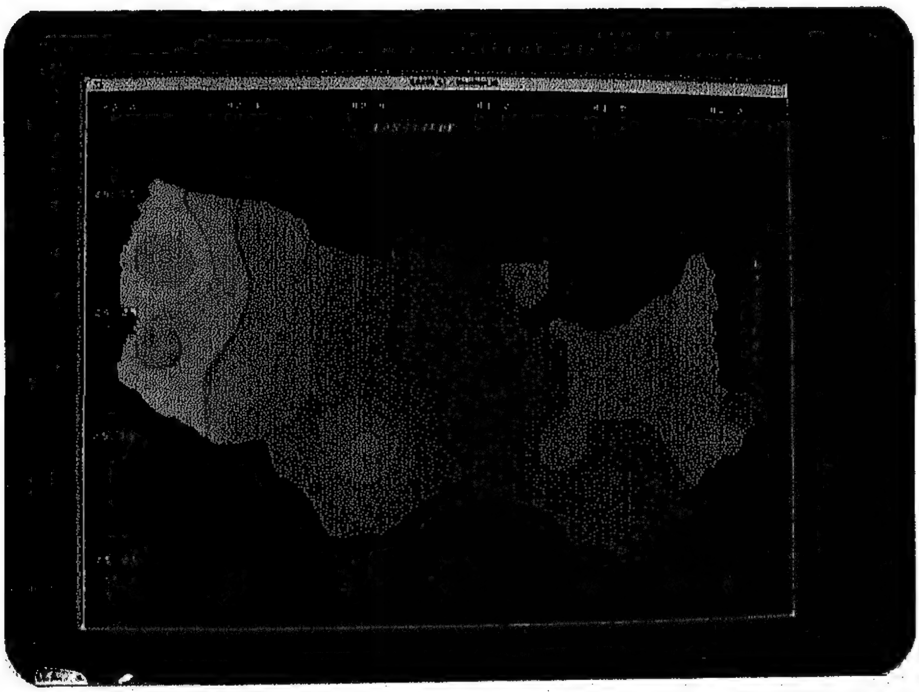

Figure 4.4: Raster Map Interpolated Rainfall Surface

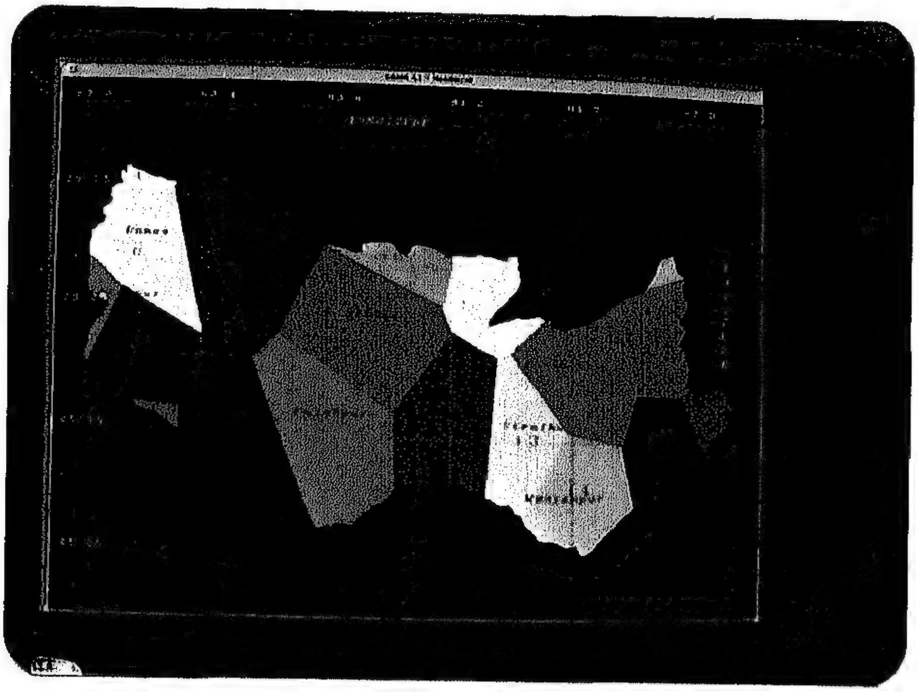

Figure 4.5: Raster Map Rainfall Theissen Polygons

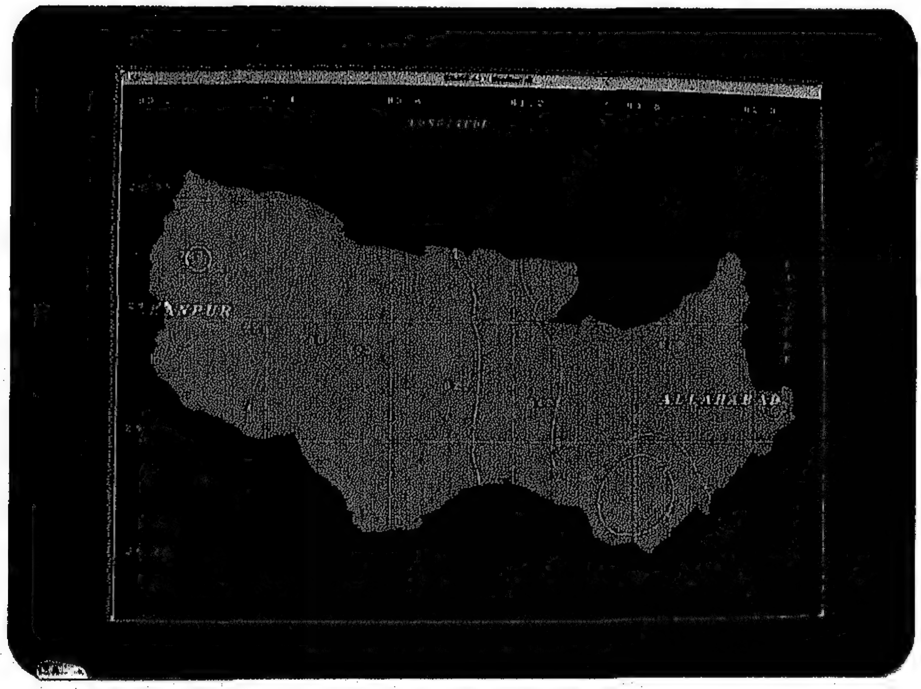


Figure 4.6: Raster Map of Rainfall Contours (monsoon)

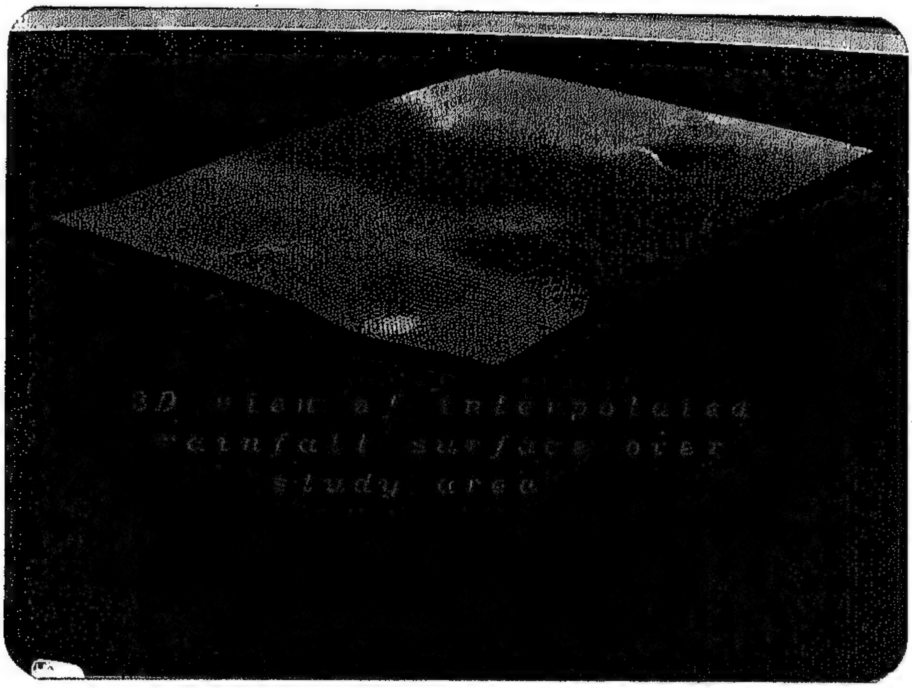


Figure 4.9: 3-D map showing rainfall distribution

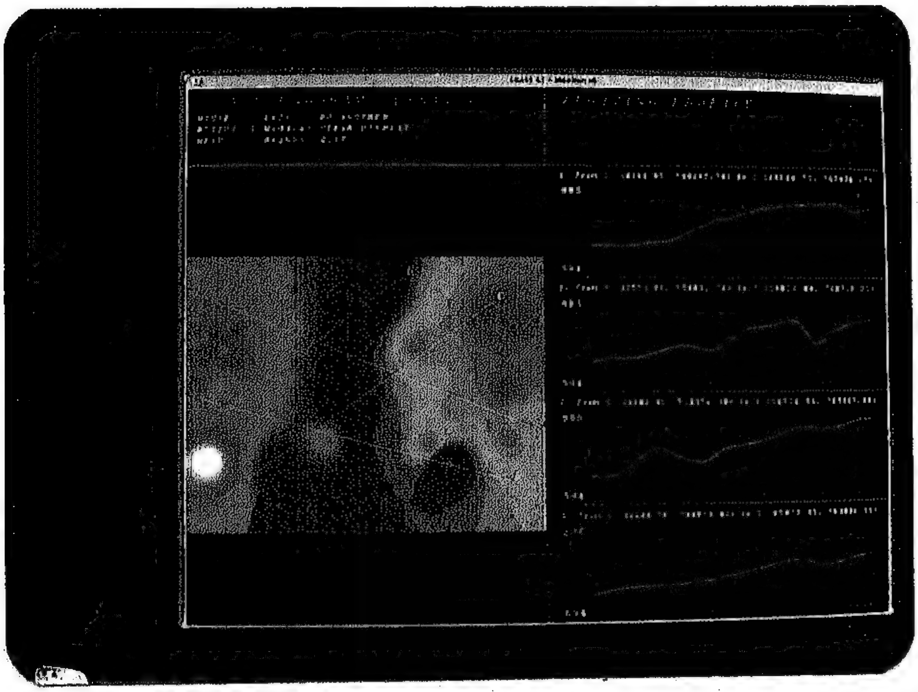

Figure 4.10: Color Photo showing the capability of *d.profile*

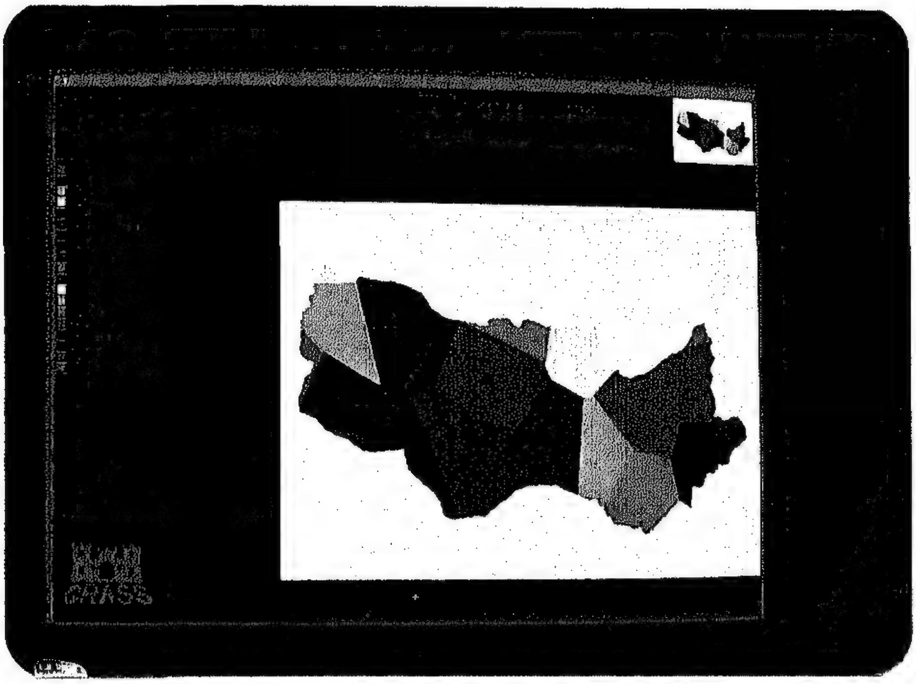

Figure 4.11: Color Photo showing the capability of *d.display*

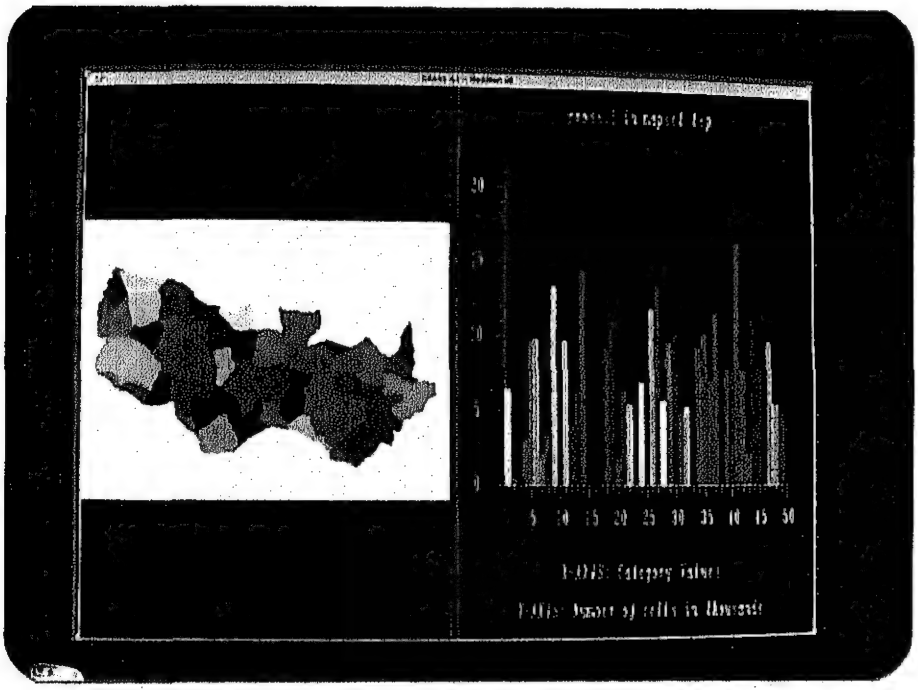

Figure 4.12: Color Photo showing the capability of *d.histogram and split.view.sh*

# Chapter 5

# Ground Water Balance

## 5.1 General

The physical and hydrologic characteristics of the study area discussed in the previous chapters provide the necessary background information for identification and estimation of different components of ground water balance The area is bounded by rivers as well as canals and there are number of small rivers also They could be important from the point of view of interaction with the ground water system However, the major contribution of ground water recharge is from rainfall over the study area, with its time and space variability The recharge from canal and ground water irrigation systems as well as field percolation from irrigated areas also constitute sources of recharge to ground water The main sources of extraction from ground water is through pumping by public and private wells.

## 5.2 Ground Water Balance Equation

The ground water balance equation over a specified time period in general terms can be stated as : change in storage volume = volume of recharge - volume of extraction After identifying the components of recharge and extraction , the above relationship can be written as

$$R_r + R_c + R_l + I_g + I_s = Tp + O_g + E_T + E_s + S_g + L$$

where,

$R_i$ = Natural recharge from precipitation

$R_c$ = Recharge due to seepage of rivers, canals, water courses, ponds etc

$R_I$ = Recharge from irrigation and other activities

$I_g$ = Inflow to ground water from other sources

$I_s$ = Influent seepage

$T_p$ = Withdrawl from ground water storage

$O_g$ = Ground water outflow from basin to other basins

$E_T$ = Evapotranspiration from ground water

$E_s$ = Effluent seepage

$S_g$ = Change in ground water storage

L = Loss through deep percolation

### 5.2.1 Lumped Model :

Spatially lumped model is considered with the entire area as a single unit and average values of parameters of the area are taken or assumed for the study.

### 5.2.2 Study Period :

Precipitation is the main source of supplies. Although its distribution varies greatly from period to period, yet the variance from year to year is not so marked and precipitation over the area under study follows a net annual pattern. The period of study for ground water balance is therefore taken as one year.

## 5.3 Recharge Components

### 5.3.1 Recharge from Rainfall

The major source of recharge of ground water is by precipitation which infiltrates through the soil horizons The amount of recharge depends on various hydromateriological, topographic, humidity, permeability conditions.The recharge due to rainfall is to be estimated generally on the basis of detailed water budget analysis which is outside the scope of the study. The following approach based on a review of available information is adopted for the study The Central Ground Water Board has conducted a number of studies and has concluded that rainfall recharge in U.P can be estimated as around 15 percent of the annual rainfall, viz

*Barber and Carr* have analyzed the data for number of wells in non canal irrigated areas and fitted a relationship.

R = 0 27 $S_y$ (1 6 $P_m$- 0.12)

Where $S_y$ is the specific yield and $P_m$ is the monsoon season rainfall in meters The value of $S_y$ ranges from 0.12 to 0 15 A value of 0.12 is considered in the present analysis.

For obtaining the value of average monsoon and non monsoon rainfalls over the entire region the program *r average* is used.

### 5.3.2 Recharge from Canals

Seepage losses from unlined canals very often constitute about 20 percent of the total diversions. U P. Irrigation Department has carried out the recharge studies on different canals and these results have been used in the present study to account for the canal recharge component in the water balance equation.

The details of recharge (district wise) are collected from U.P.Irrigation department and are implemented in the data base. The average of these recharges is calculated from the utility *r.average and r.mapcalc.*

### 5.3.3 Recharge from field percolation

The percolation from irrigated fields could not be estimated accurately for different crops in view of limitation of data and time Generally percolation loss is expected to be the highest for paddy and the lowest for wheat and is likely to vary between 20 to 40%. A value of 20% is adopted in this study.

## 5.4 Abstraction Components

The abstraction from the ground water system mainly consist of the extraction by wells Besides this the utilization of ground water directly by free standing trees, and consumptive use by vegetation either beneficial or non-beneficial from shallow water table areas is also important For estimation of these components the available data for the year 1991 were implemented in the data base and the total recharge has been found out using the utility *r mapcalc.*

### 5.4.1 Extraction by Wells

U P Irrigation Department has provided the data of extractioins from various public tube wells, private tube wells, pump sets etc and their estimated draft rates for monsoon and nonmonsoon seasons. The withdrawl values for the year 1991 were incarporated in this study and are used as an important abstraction

### 5.4.2 Evapotranspiration

The evapotranspiration from the ground water is essentially at potential rate from lakes and other water bodies and shallow water table areas near rivers and canals at a depth of less than 1m below ground level.

From the water table surface and topography a depth to water table map is prepared and the area contributing to potential evapotranspiration is evaluated. The total evapotranspiration from shallow water table is determined for the two seasons *Blaney-Criddle* formula is used to calculate the evapotranspiration values for different

| consumptive use coefficient for different months | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Rice | | | 0.85 | 1.00 | 1.15 | 1.30 | 1.25 | 1.10 | 0.90 | | | |
| wheat | 0.5 | 0.7 | 0.75 | 0.7 | | | | | | | | |
| Sugarcane | 0.75 | 0.80 | 0.85 | 0.85 | 0.90 | 0.95 | 1.00 | 1.00 | 0.95 | 0.90 | 0.85 | 0.75 |

Table 5.1: Consumptive use coefficient k for use in *Blaney-Criddle*'s formula

crops.

$$u = \frac{\sum k\ t\ p}{100} mm \tag{5.1}$$

where, u=monthly consumptive use

k=consumptive use factor

p=monthly percentage of daytime hours of the year

t=mean monthly temparature

Table5.1. gives the monthly consumptive use crop coefficient k for use in *Blaney-Criddle* formula (after *Dastane, 1972*)

### 5.4.3 Effluent Seepage:

The ground water is discharged from the basin by seepage to streams. The river could be effluent and influent depending on the relative levels of the water table and river stages and the intersection of the aquifer by the stream. The water table and river stages fluctuate. The river stage may rise above the water table during the monsoon but would generally be below the water table during the nonmonsoon period. As such water may be discharged from an aquifer to the stream during nonmonsoon period, while for part of period it may seep from the river to aquifer during monsoon period. The effluent or influent character of the river therefore varies from season to season and from reach to reach. In several rivers the dry weather flow is due to the base flow from the ground water and this is also true for rivers Ganga, Yamuna, and Hindon etc. In the study area the real situation in a river is very complicated. Hence the estimation of regenerated base flow except on the basis of actual observations is very

difficult or has to be done with utmost care. In the present study due to the limitation of data and time, the base flow has been approximated for the ground water balance study.

### 5.4.4 Soil Moisture storage :

The water stored in the unsaturated zone of the soil varies as a result of evaporation and transpiration. This soil moisture content can be found out by different methods such as gravimetric method , Isometric method etc., But normally the soil moisture content is not likely to change form year to year The change in soil moisture content is therefore neglected in the study

## 5.5 Ground Water Balance For Monsoon and Non-monsoon Seasons

A number of components of the ground water balance for monsoon and non monsoon seasons have been evaluated and are shown in Table 5.2. However influent seepage, Ground water inflow or outflow soil moisture storage change were not available for the study and so the ground water balance could not be verified.

| Ground Water components for Monsoon season | Hectare-m |
|---|---|
| Recharge due to monsoon rainfall | 359722 |
| Recharge due to canals,tubewells,irrigation | 390166 |
| Total Monsoon Recharge | 749888 |
| Ground Water Draft | 102700 |
| Evapotranspiration | 342085 |
| Monsoon season withdrawl | 444785 |

| Ground Water components for Nonmonsoon season | Hectare-m |
|---|---|
| Available Groundwater Recharge | 305013 |
| Recharge due to Nonmonsoon rainfall | 23251 |
| Recharge due to canals,tubewells,irrigation | 38033 |
| Total Nonmonsoon Recharge | 367187 |
| Ground Water Draft | 205400 |
| Evapotranspiration | 204648 |
| Effluent Seepage | 80000 |
| Nonmonsoon withdrawl | 490048 |

| | |
|---|---|
| Monsoon seasonal difference | 305103* |
| Nonmonsoon seasonal difference | −123861* |
| Ground water storage change | 463607* |

Table 5.2: Ground water balance

* Difference between these terms may be due to terms not calculated.

# Chapter 6

# Conclusions

## 6.1 Summary

The Geographical Information Systems are a powerful set of tools for collecting, storing, retrieving at will, tranform ing and displaying spatial data from the real world for a particular set of purposes.Additional components of GRASS4.1, a raster based, already implemented (partly) GIS were implemented in SPARC LX workstation at Water Resources engineering and management centre, Department of Civil Engineering, I.I.T., Kanpur. The software XGRASS4.1 is tested for its application. Then GRASS4.1 and XGRASS4.1 were used for the hydrologic database creation and analysis of ground water balance components in the ganga river basin between Kanpur and Allahabad

## 6.2 Conclusions

GRASS is a versatile software for development of spatial database and its analysis. In the present study almost all the utilities of this software have been used for the creation, analysis and representation of the database.The created database can be used for further analysis very easily.Since GRASS has been written in C language with facility for shell scripting and implemented in a window environment in a network accessible form, it provides an extremely versatile and powerful environment for G.I.S.

and spatial decision support systems in water resources and Civil Engineering systems, planning, design,development and management.

- The Ground water balance study can be used for planning the irrigation developmental alternatives
- The created water resources data base can be utilized for other hydrologic analysis with limited effort.
- Accurate measurement of influent and effluent seepage can be done to arrive at an exact ground water balance study.
- Ground water balance study using a lumped model is a crude method Distributed model study will give better ground water balance in the study area

## 6.3 Suggestions for further study

Presently paper maps prepared by Irrigation Department are used as input to G I S It's production and collection takes a considerable time These difficulties can be avoided by using digital cartographic data or remotely sensed images Moreover remotely sensed images tend to decrease the time required for the analysis

The soil characteristics at different irrigation blocks can be collected to get the detailed information about the specific yield at those areas and these specific yield values can be adopted to get the exact ground water balance for the study region.

The run-off data may be collected or can be modelled and can be added to the present data base to be used for the complete water budget analysis of the study region.

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